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The Kingdom of Norway

PCT/NO 00 0 002 19
10/018460

REC'D 03 JUL 2000

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4

NO00/219

Bekreftelse på patentsøknad nr

Certification of patent application no

1999 3135

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2000.06.27

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PATENTSTYRET

Styret for det industrielle rettsvern

Søknad om patent

Søknadsskriv

la - i

23 JUN 99 993135

Utfylles av styret

Behandlermedlem EH

Int. Cl⁸ G02F

Søkers/fullmektigens referanse
(angis hvis ønsket):

NNP99169D

Oppfinnelsens
benevnelse:

Fremgangsmåte for polarisasjonskontroll.

Hvis søknaden er
en internasjonal søknad
som videreføres etter
patentlovens § 31:

Den internasjonale søknads nummer

Den internasjonale søknads inngivelsesdag

Søker:
Navn, bopel og adresse.
(Hvis patent søkes av flere:
opplysning om hvem som skal
være bemyndighet til å motta
meddelelser fra Styret på vegne
av søkerne).

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Prioritet kreves fra dato sted nr.

Prioritet kreves fra dato sted nr.

Prioritet kreves fra dato sted nr.

Hvis avdelt søknad:

Den opprinnelige søknads nr.: og deres inngivelsesdag

Hvis utskilt søknad:

Den opprinnelige søknads nr.: begjært inngivelsesdag

Deponert kultur av
mikroorganisme:

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Utlevering av prøve av
kulturen:

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993135

Angivelse av tegnings-
figur som ønskes
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Fig. nr.

Background

This invention is related to the elimination of polarization fading in unbalanced optical measuring interferometers.

An optical interferometer is an optical transmission network that produces interference
 5 between different portions of optical radiation that have traveled different paths through the network. In a two-arm unbalanced optical interferometer, the time delay in the two optical paths are different by an amount τ . The output intensity from such an interferometer will have a periodic dependence called fringes of the output intensity that is periodic versus the
 10 interferometer phase delay $\phi = 2\pi\nu\tau$, where ν is the optical frequency launched into the interferometer. Information about the path delay difference, the input optical frequency, or the input optical frequency spectrum may thus be deduced from the output interference signal.

An optical interferometer network may also contain more than one pair (or set) of paths from the input to the output port. Different pairs (or set) of paths may then be interpreted as different interferometers. The interference caused by individual interferometers may be
 15 interrogated separately

- a. by assigning a specific range of optical wavelengths to the transmission in at least one path associated with each interferometer, thus employing a wavelength division multiplexing (WDM) technique,
- b. by assigning a specific range of total transmission time delay to the paths associated
 20 with each interferometer, thus employing a time division multiplexing (TDM) technique,
- c. or by assigning a specific combination of input and output ports to the paths associated with each interferometer, thus employing a space division multiplexing (SDM) technique. An SDM system may for instance be interrogated by using optical switches
 25 to access different combinations of input and output ports sequentially, or by splitting the optical radiation from a single interrogating source into different interferometer sub-networks, and connecting one detector to the output of each sub-network.

Network interrogation employing combinations of WDM, TDM and SDM is also possible.

The visibility or amplitude of the output fringes from an interferometer depends on the
 30 states of polarization (SOPs) of the two interfering signals, which for a two-path interferometer may be labeled SOP1 and SOP2. In many interferometers SOP1 and SOP2 will

vary randomly with time due to changes in the input SOP or in the birefringence properties of the two optical pathways. The fringe visibility is proportional to the projection of SOP1 onto SOP2. The reduction of fringe visibility with reduced projection of the SOPS is called polarization fading, and generally causes a reduced signal to noise ratio in the interferometer readout. Especially, the situation with $SOP1 \perp SOP2$ (orthogonal SOPs) causing total polarization fading with zero visibility should be avoided. When the fading is total, the interferometer output will not carry any information about ν or τ at all.

Several methods for reduction or elimination of the polarization fading problem are known. One known method uses Faraday rotating mirrors, as disclosed by A.D. Kersey et. al. in ["Polarisation insensitive fibre optic Michelson interferometer", *El. Lett.*, Vol. 27, pp. 518-19, 1991]. This method allows for a simple source and detection system, but it works only for the Michelson interferometer configuration. Furthermore, the Faraday rotating mirrors may be expensive, space consuming, and sensitive to extreme thermal, electromagnetic and other environmental conditions.

Other known methods are based on active polarization control at the input, as disclosed by A. D. Kersey et. al. in ["Optimization and Stabilization of Visibility in Interferometric Fiber-Optic Sensors Using Input-Polarization Control", *J. of Lightwave Technol.*, Vol. 6, pp. 1599-1609, 1988], or the use of a polarizer combined with active polarization control at the output end, as disclosed by K. H. Wanser et. al. in ["Remote polarization control for fiber-optic interferometers ", *Opt. Lett.*, Vol: 12, pp. 217-19, 1987]. In both cases the polarization controller is continuously adjusted to optimize the fringe visibility. These techniques require relatively complex systems to provide feedback signals to the polarization controller, and in systems with spatial division multiplexing (SDM) or wavelength division multiplexing (WDM) of multiple sensors, individual polarization controllers for each sensor are generally required. The polarization modulator used for the polarization control must be capable of modulating the SOP in three dimensions on the Poincaré sphere. This generally implies that the polarization modulators at least must be of the "dual stage" type. Dual stage polarization modulators generally incorporate two independently adjustable birefringent elements, and are thus more complex and expensive than single stage modulators having only one adjustable birefringent element.

Still other known methods are based on modulating the input SOP between three states, as disclosed by A. D. Kersey et. al. in ["Input polarisation scanning technique for overcoming polarisation-induced signal fading in interferometric fiber sensors ", *El. Lett.*, Vol. 24, pp.

931-33, 1988] and in [US Patent No. 4 932 783], or on the use of three detectors at the output with three polarizers that are adjusted to monitor different polarization states, as disclosed by N. J. Frigo et. al. in ["Technique for elimination of polarisation fading in fibre interferometers", El. Lett., Vol. 20, pp. 319-20, 1984]. These techniques increase the complexity of the processing by requiring simultaneous processing of three fringe signals, especially in WDM systems where separate receivers are required for each WDM channel. They also increase the complexity of the hardware by either requiring a dual stage polarization modulator, or three detectors and polarizers.

Another known method is based on the use of a pulsed source and a compensating interferometer which incorporates a polarization maintaining coupler, a standard coupler, and a polarization modulator, as disclosed by B. Y. Kim et. al. in [US Patent No. 5 173 743]. This method may be attractive when applied to time division multiplexed (TDM) ladder sensor networks. However, the compensating interferometer increases the complexity of the interrogation, and 3 dB of source power is lost in the output coupler from the compensating interferometer. If the network is not of the ladder type, another 3 dB of optical power will be effectively lost at the detector, since only one half of the detected pulses will carry useful information. Another problem with this method is that readout phase from the interferometer is sensitive to birefringence changes in the lead fiber between the source and the interferometers.

One sensor configuration of special interest is that of a WDM fiber-optic interferometric sensor system employing two identical wavelength selective low reflectivity fiber Bragg grating reflectors to define the two paths of each sensor interferometer. For instance, a Fabry-Perot interferometer can be formed by writing two identical Bragg gratings into the core of a single optical fiber at different locations. Different reflection bands should be dedicated to each sensor, so that information about the individual sensors can be accessed by use of a multi-wavelength source at the network input producing coherent radiation at each sensor wavelength, and a wavelength division multiplexer at the network output, that directs the interference signal from each sensor to a dedicated detector.

Objective

The main objective of the present invention is to provide a simple and practical method, with reduced complexity compared to existing techniques, which eliminates or reduces the probability for polarization induced fading in optical interferometers. This objective implies that the output signals from the interferometer always should carry the information required to determine the difference in optical path length, or optical phase, between two different paths through the interferometer.

A second objective of the present invention is to provide a method which allows the readout interferometer phase to be insensitive to birefringence changes in the lead fiber between the source and the interferometer.

A third objective of the present invention is to provide a method which can be applied to interrogation of any type of unbalanced interferometer that do not contain polarization selective components, such as polarizers or polarization beam splitters. This class of interferometers includes variants of the Fabry-Perot, Michelson, and Mach-Zender geometries. The method should also be applicable in interrogation systems where a compensating interferometer is used in combination with a pulsed source in order to compensate for the imbalance of the interrogated interferometer(s).

A fourth objective of the present invention is to provide a method which can be applied to interrogation of wavelength division multiplexed (WDM), space division multiplexed (SDM), and time division multiplexed (TDM) interferometer networks, including TDM ladder networks.

A specific objective of the present invention is to provide a method which can be applied to interrogation of fiber optic WDM sensor systems employing wavelength selective Bragg reflectors in the sensing interferometers and a multi-wavelength source. The method should require only one polarization modulator for the entire system, and only one detector dedicated to the monitoring of each sensor.

A general objective of the present invention is to provide a method that overcomes limitations set by other known methods.

Invention

The objective of the invention is achieved with a method having features as stated in the characterizing part of Claim 1. Further features are stated in the dependent claims. The main part of the invention is characterized in that the polarization state of the optical power

5 launched into an interferometer network is modulated at a frequency comparable to or higher than the inverse of the difference in transmission time delay between the two optical paths through the interferometer. A control and signal processing unit extracts several interference signals detected at the output of the interferometer network in at least two time slots, that are positioned in time at certain time delays (or phases) relative to the input polarization

10 modulation period. The time slots should be chosen such that the two optical signals interfering at the output port after having traveled the two paths through the interferometer, originate from different combinations of input polarization states in each time slot, and such that total polarization fading of the interference visibility never will occur simultaneously in all time slots. Minimization of the sensitivity of the readout interferometer phase to

15 birefringence changes in the path from the interrogating optical source to the interferometer can be achieved by modulating the input polarization between two orthogonal polarization states and by processing signals from four distinct time slots.

Detailed description of the invention

Fig. 1 illustrates a preferred embodiment of this invention, including the interrogated interferometer network (3), incorporating a Fabry-Perot interferometer.

Fig. 2 illustrates a typical evolution of the input and output states of polarizations (SOPs) versus time.

Fig. 3 illustrates alternative embodiments of the interferometer network (3) in Fig. 1, incorporating (a) a Michelson interferometer and (b) a Mach-Zender interferometer.

Fig. 4 illustrates an alternative embodiment of the invention, demonstrating interrogation of multiple wavelength division multiplexed interferometers.

In the preferred embodiment of this invention, illustrated in Fig. 1, an optical source (1) launches coherent optical radiation into the fiber-optic sensor network (3) through a polarization modulator (2). The sensor network (3) consists of an input-output optical coupler (4) with a 50% power splitting ratio, a lead fiber (5) and a low finesse Fabry-Perot (FP) interferometer (6) consisting of two reflectors (7,8) and a fiber delay line (9) with dual-pass delay τ . The power reflectivities of (7) and (8) should preferably be small ($<10\%$), allowing multiple mirror reflections to be neglected. The output power from the network (3) is guided to a photo-detector, and the resulting analog electrical signal is transferred to the analog to digital conversion interface of a control & signal processing unit (11), which is responsible for processing the detected signals electronically to extract the interferometer phase information, and for transferring this information in a suitable form to the end user.

The control & signal processing unit (11) also controls the polarization modulator (2) and causes the input polarization state SOP0 launched into (3) to switch between two orthogonal states, denoted SOP0A and SOP0B in Fig. 2. The polarization switching period should equal 4τ , and the duty-cycle of the modulation should be 50%, as illustrated by the top curve in Fig.

2. The coupler (4), the lead fiber (5), the interferometer fiber (9), and the reflectors (7,8) should preferably have negligible polarization dependent losses. The latter condition implies that the polarization states SOP1 and SOP2 reflected from (7) and (8), respectively, and interfering at the left hand side of (7) in Fig. 1, will also both be switching between pairs of orthogonal states, denoted SOP1A, SOP1B, SOP2A, and SOP2B in Fig. 2. SOP1A and SOP1B may then generally be written in a Jones-vector notation as

$$\text{SOP1A} = \bar{A} = K_1 \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha)e^{i\gamma} \end{bmatrix}, \quad \text{SOP1B} = \bar{B} = K_1 \begin{bmatrix} -\sin(\alpha)e^{-i\gamma} \\ \cos(\alpha) \end{bmatrix},$$

where the vector elements are chosen to represent the projections of the fields onto the orthogonal eigen-polarization states of the interferometer. By the interferometer eigen-polarization states we mean the output SOP1 generated when SOP0 is adjusted so that SOP1 = SOP2. K_1 depends on the source power, the losses in the transmission through (4,5), and the losses in the reflection (7). α and γ are angles that depend on the birefringence properties of the lead fiber.

The chosen polarization projection states allow SOP2A and SOP2B to be written on the form

$$\text{SOP2A} = \mathbf{J}\bar{A} = K_2 e^{i\phi} \begin{bmatrix} \cos(\alpha) \\ \sin(\alpha)e^{i(\gamma+\theta)} \end{bmatrix}, \quad \text{SOP2B} = \mathbf{J}\bar{B} = K_2 e^{i\phi} \begin{bmatrix} -\sin(\alpha)e^{-i\gamma} \\ \cos(\alpha)e^{i\theta} \end{bmatrix},$$

where the Jones matrix

$$\mathbf{J} = e^{i\phi} \begin{bmatrix} 1 & 0 \\ 0 & e^{i\theta} \end{bmatrix}, \quad (\text{Eq. 1})$$

essentially describes difference between the SOP changes from SOP0 to SOP1 and that from SOP0 to SOP2. $\phi = 2\pi\tau\nu$ is the interferometer phase that we want to measure, ν is the optical frequency, and θ is the birefringent phase-shift between the eigen-polarization states of the interferometer. K_2 depends on losses in the transmissions and reflection in (8,9).

The two lower curves in Fig. 2 illustrate the switching of SOP1 and SOP2. A periodic pattern consisting of 4 time slots can be observed, where:

- SOP1A interferes with SOP2A in slot1,
- SOP1B interferes with SOP2A in slot2,
- SOP1B interferes with SOP2B in slot3,
- SOP1A interferes with SOP2B in slot4.

The interference power will be composed by one interference term that depends on ϕ , θ , γ , and α , and another term that is independent on these parameters. The power from each time slot n will produce an electrical signal S_n at the detector output, which is proportional to the interference power.

We may then write

$$\begin{aligned}
 S_1 &= 2K_3 \operatorname{Re}\{\bar{A}^+ \mathbf{J} \bar{A}\} = a \cos(\phi_1) \\
 S_2 &= 2K_3 \operatorname{Re}\{\bar{B}^+ \mathbf{J} \bar{A}\} = b \cos(\phi_2) \\
 S_3 &= 2K_3 \operatorname{Re}\{\bar{B}^+ \mathbf{J} \bar{B}\} = a \cos(\phi_3) \\
 S_4 &= 2K_3 \operatorname{Re}\{\bar{A}^+ \mathbf{J} \bar{B}\} = b \cos(\phi_4),
 \end{aligned} \tag{Eq. 2}$$

where K_3 accounts for the detector responsivity and losses in (4,5), superscript $+$ indicates conjugate transpose,

$$\begin{aligned}
 \phi_1 &= \phi + \theta + \varphi \\
 \phi_2 &= \phi + \theta/2 + \gamma - \pi/2 \\
 \phi_3 &= \phi - \varphi \\
 \phi_4 &= \phi + \theta/2 - \gamma - \pi/2
 \end{aligned}
 , \text{ and } a^2 + b^2 = K_1 K_2 K_3^2. \tag{Eq. 3}$$

φ is a function of θ and α .

10 The control & signal processing unit extracts the fringe signals S_1 through S_4 and processes them to determine the phases ϕ_1 through ϕ_4 . Note that the detected signals are delayed relative to the control signals supplied to the polarization modulator. Some calibration of the input slot timing is therefore required. Several methods are known for phase reconstruction without ambiguity from interference signals, as disclosed for instance by I. J. Bush in ["High performance interferometric demodulation techniques", SPIE Proc., Vol. 1795, pp. 412-20, 1992]. Generally, these methods require means for modulating the interference phase to generate in-phase and quadrature information from the interference fringes. In the preferred embodiment of the present invention this can be achieved by modulating the phase of the source radiation at a frequency that is an odd harmonic of $1/(4\tau)$.

20 We see from (Eq. 2) that the detected fringe amplitudes equal a in slots 1 and 3, and b in slots 2 and 4. Since $a^2 + b^2 = K_1 K_2 K_3^2$ according to (Eq. 3), there can never be fading simultaneously in two neighboring time slots, and the sum of the signal to noise ratios of two neighboring time slots, limited by the fringe amplitude, will be independent on the birefringence parameters θ , γ , and α . Thus, the main objective of the present invention is satisfied.

25 It remains to combine the information carried by ϕ_1 , ϕ_2 , ϕ_3 , and ϕ_4 into one single estimate for the interferometer phase delay, which according to (Eq. 1) is ϕ for one eigen-

polarization and $\phi + \theta$ for the other eigen-polarization. In the preferred embodiment, the estimator

$$\Phi = \frac{a^2(\phi_1 + \phi_2) + b^2(\phi_3 + \phi_4)}{a^2 + b^2} \quad (\text{Eq. 4})$$

is computed by the control & signal processing unit to estimate the interferometer phase delay. By combining (Eq. 3) and (Eq. 4) we see that Φ in the absence of noise equals $\phi + \theta/2$, which is exactly the mean of the two eigen-polarization phase delays. Φ is independent on the birefringence parameters γ and α of the lead fiber, and thus the second objective of the present invention is satisfied. The weighting in (Eq. 4) of $\phi_1 + \phi_2$ and $\phi_3 + \phi_4$ by a^2 and b^2 , respectively, ensures that the signal to noise ratio of the estimator always will be close to a maximum.

The present invention may be implemented for interrogation of any types of unbalanced interferometer networks that do not contain polarization selective components such as polarizers or polarization beam splitters. As one example, Fig. 3 (a) illustrates a network incorporating a Michelson interferometer, which may replace the network (3) in Fig. 1 in a second embodiment of the present invention. SOP0 is launched into the input/output coupler (4) and the lead fiber (5), which both have the same functions as in Fig. (1). The Michelson interferometer (12) is formed by an optical coupler (13) splitting the optical power from (5) into two delay arms, with reflectors (14,15) positioned at different distances from (13) so that the dual path time delays experienced by the two reflected signals recombined in (13) differ by τ . SOP1 and SOP2 in this case refer to the polarization states recombined in (13) after returning from the short delay arm with reflector (14) and the long delay arm with reflector (15), respectively.

As another example, Fig. 3 (b) illustrates a network incorporating a Mach-Zender (MZ) interferometer, which may replace the network (3) in Fig. 1 in a third embodiment of the present invention. This system has separate input (16) and output (22) lead fibers. SOP0 is launched into (16). The MZ interferometer (17) is formed by an optical coupler (18) splitting the optical power from (16) into two delay arms (19,20). The signals emerging from (19) and (20) are combined in a second optical coupler (21). The single pass time delays between (18) and (21) through (19) and (20) should differ by τ . SOP1 and SOP2 in this case refer to the polarization states entering (21) from the short (19) and long (20) arms, respectively.

Fig. 4 illustrates a fourth embodiment of the present invention capable of wavelength division multiplexing of several wavelength selective interferometers. In the illustrated

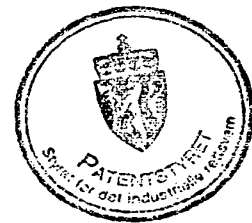
example, a multi-wavelength source (23) is used, launching coherent radiation at three sensor interrogation wavelengths λ_1 , λ_2 , and λ_3 through the polarization modulator (2) into the interferometer network (24). The input polarization of all wavelengths is switched simultaneously between orthogonal states, in the same way as explained for SOP0 in the preferred embodiment of the present invention. The network contains an input/output coupler (4), a lead fiber (5) and three FP-interferometers with approximately equal dual-pass delay τ . Each FP-interferometer consists of two identical Bragg gratings, denoted (25), (26) or (27), causing a weak reflection in a narrow band around the respective sensor interrogation wavelength λ_1 , λ_2 , or λ_3 . Each sensor grating pair should produce negligible reflections at the interrogation wavelengths of the other sensors. A wavelength demultiplexer (28) is connected to the output branch of (4), distributing the interference signals from the different interferometers to different detectors (29, 30, 31). The control & signal processing unit (32) processes the three detector signal sequences in parallel, in the same way as explained for the single processing channel in the preferred embodiment, to extract the individual interference phases of the three interferometers and present this information for the end user.

The network (23) in Fig. 4 can be interrogated by a time division multiplexing (TDM) approach using the present invention, provided that all reflectors reflect on the same wavelength, i.e. either $\lambda_1 = \lambda_2 = \lambda_3$ or the gratings must be replaced with broad-band reflectors, and that the dual pass delay from the input/output coupler (4) to the beginning of different interferometers differ by at least the order of 3τ . A possible sixth embodiment of the present invention may then use a pulsed single wavelength source at wavelength λ_1 , and only one detector without any wavelength demultiplexer in front, like the detector (10) in Fig. 1. The source and polarization modulator produces pulses with a duration of minimum 2τ , with polarization state switching between orthogonal states within each pulse at a frequency that is an odd harmonic (or multiple) of $1/(4\tau)$ and which is higher than the inverse pulse duration, as illustrated for SOP0 in Fig. 2. The detected signal will consist of one time sequence for each pulse transmitted from the source, each sequence containing at least 4 time-slots originating from each sensor interferometer. The time slots contain information about the interference phases of individual sensors, encoded in the same way as for the output time-slot signals described in the preferred embodiment. The control & signal processing unit may thus extract the interference phases by separating, identifying and processing the information originating from each sensor in the same way as described for the preferred embodiment.

A special case of TDM interferometer networks are ladder interferometer networks, with geometries of the type described in [US Patent No. 5 173 743, Fig.1, items (26), (27 a, b, c, d), (28), and (31 a, b, c, d)]. In a ladder network, the input to output delay of a number N of interferometer arms are equally spaced by the amount of time τ , and all paths, except for two, are thus part of two interferometers at the same time. The current invention can be used for interrogation of such ladder networks, including a compensating interferometer with imbalance τ placed after the source, as illustrated in [US Patent No. 5 173 743, Fig.1, items (20, 21, 22, 23, 25)]. Each pulse from the source should have duration equal to τ , and will thus be split into two by the compensating interferometer. The polarization modulator can be placed between the source and the compensating interferometer. Polarization maintaining fibers and couplers should be used in the compensating interferometer to ensure that the polarization of the two consecutive pulses emerging from the compensating interferometer will switch between identical pairs of orthogonal polarization states. Alternatively, an imbalanced Michelson interferometer with Faraday-rotating mirrors, and otherwise standard fibers and couplers, may be used as compensating interferometer.

The current invention may also be used for interrogation of ladder networks without the inclusion of any compensating interferometer. The duration of each pulse from the source should in this case be close to 2τ .

Although coherent sources have been assumed in all the previous examples, the present invention can also be used in a white-light interferometer that is interrogated, for instance, by scanning the path-imbalance of a compensating interferometer.



Patent Claims

1. A method for sustained elimination or reduction of polarization induced signal fading in optical interferometer networks where at least two optical paths from an input port to an output port of said network have transmission delays that differ by an amount of time τ , and where the optical phase difference induced between optical waves that have traveled the said at least two paths is interrogated by an arrangement, said arrangement containing at least one optical source launching optical power into said input port, a detector arrangement converting the optical power received from said output port into electrical detector signals, and control and signal processing units capable of processing the said detector signals to determine the said phase difference,

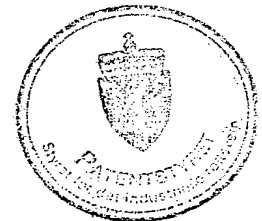
characterized in that the input polarization state produced by the source changes between different polarization states with a modulation frequency that preferably should be an odd multiple of $1/(4\tau)$, and further characterized in that at least two interference signals, that are separated in time in the said detector signals, are extracted and processed by said control and signal processing units, where last said interference signals represent interference between polarization states at said output port that originate from the transmission of different combinations of said input polarization states along the said at least two paths, thus ensuring that there will never be simultaneous polarization fading in all said extracted interference signals.
2. A method according to claim 1,

characterized in that the input polarization state produced by the source changes between two different states, called SOP0A and SOP0B, and further characterized in that four interference signals labeled (i), (ii), (iii), and (iv) that are separated in time, representing interference between polarization states at said output port that originate from the transmission of

 - (i) SOP0A through the short and SOP0A through the long interferometer path,
 - (ii) SOP0B through the short and SOP0A through the long interferometer path,
 - (iii) SOP0B through the short and SOP0B through the long interferometer path, and
 - (iv) SOP0A through the short and SOP0B through the long interferometer path,

respectively, are extracted by said control and signal processing unit and further processed to produce estimates for the interference phases of the four last said interference signals.

3. A method according to claim 2,
characterized in that the interference visibilities or fringe amplitudes of the four said interference signals (i), (ii), (iii), and (iv) are calculated.
- 5 4. A method according to claim 3,
characterized in that said SOP0A and SOP0B are orthogonal polarization states, and that a first improved phase estimate, named Φ_1 , is calculated as the average of the two said interference phase estimates produced from (i) and (iii), and that a second improved phase estimate, named Φ_2 , is calculated as the average of the two said interference phase
10 estimates produced from (ii) and (iv), and that a combined phase estimate is calculated as a weighted average of Φ_1 and Φ_2 , where the ratio between the weighting of Φ_1 and the weighting of Φ_2 is decided from the relation or ratio between the said calculated interference visibilities or fringe amplitudes.
- 15 5. A method according to claims 1, 2, 3, or 4
characterized in that the method is applied to interrogate a wavelength division multiplexed interferometer network.
- 20 6. A method according to claims 1, 2, 3, or 4
characterized in that the method is applied to interrogate a time division multiplexed interferometer network.
- 25 7. A method according to claims 1, 2, 3, or 4
characterized in that the method is applied to interrogate space division multiplexed interferometers networks.



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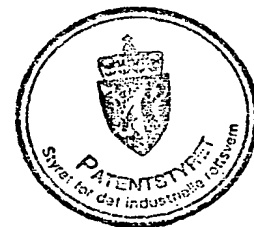
Søknad om patent

Title: "Elimination of polarization fading in unbalanced interferometers by modulation of the input polarization"

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10 Abstract

A method for minimizing polarization induced signal fading in optical interferometers, and a method for minimizing the sensitivity of the readout interferometer phase to birefringence changes in the path from the interrogating optical source to the interferometer is disclosed. This is achieved by modulating the optical polarization state launched into the interferometer network at a frequency that is comparable to or higher than the inverse of the difference in transmission time delay between the two optical paths through the interferometer. A control and signal processing unit extracts at least two interference signals detected at the output of the interferometer network in at least two time slots that are positioned in time at certain time delays (or phases) relative to the input polarization modulation period. The time slots should be chosen such that the two optical signals interfering at the output port after having traveled the two paths through the interferometer, originate from different combinations of input polarization states in each time slot, and such that total polarization fading of the interference visibility never will occur simultaneously in all time slots. Minimization of the sensitivity of the readout interferometer phase to birefringence changes in the path from the interrogating optical source to the interferometer can be achieved by modulating the input polarization between two orthogonal polarization states and by processing signals from four distinct time slots.



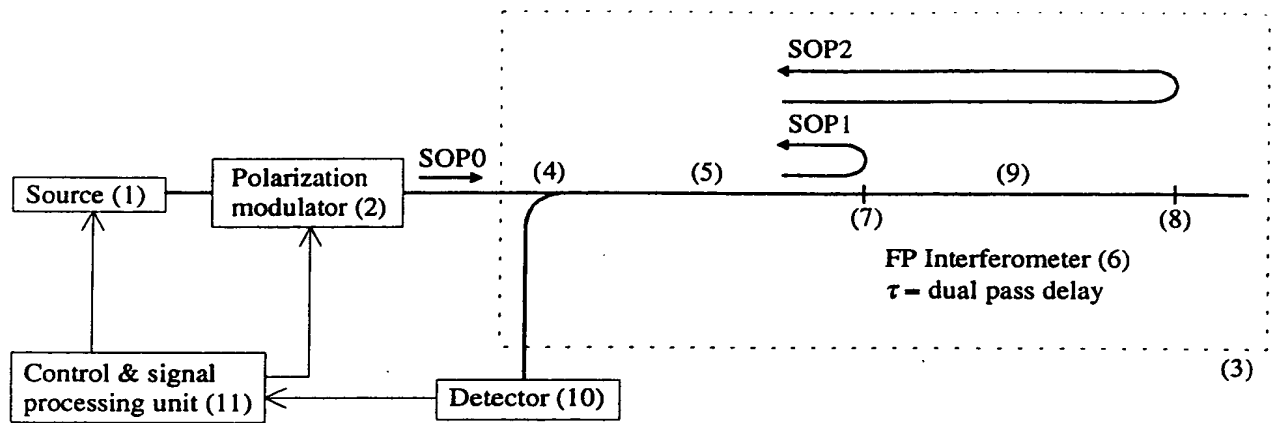


Fig. 1

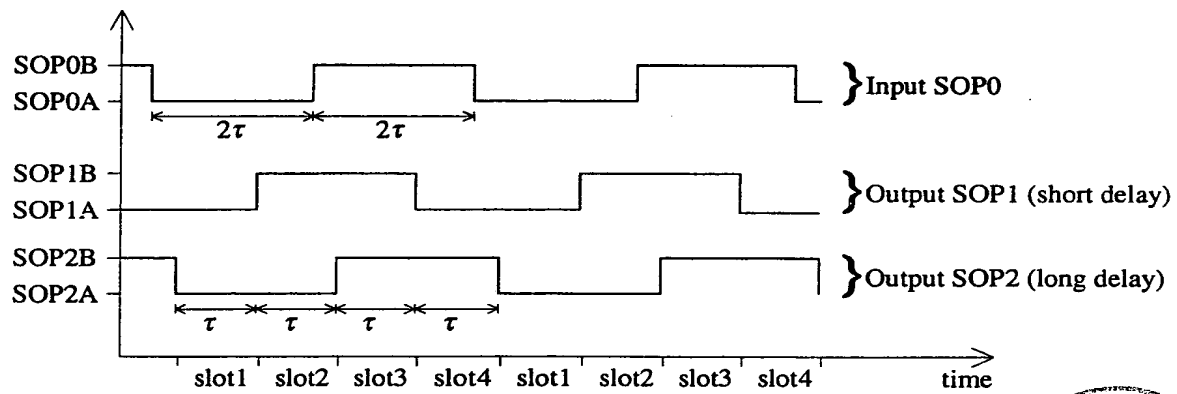


Fig. 2



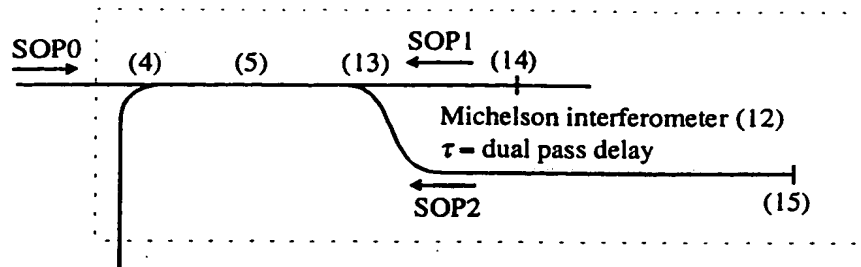


Fig. 3 (a)

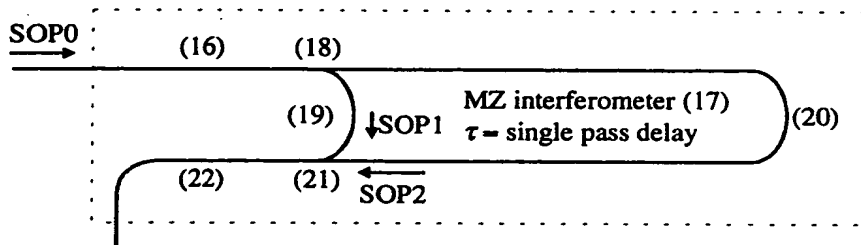


Fig. 3 (b)

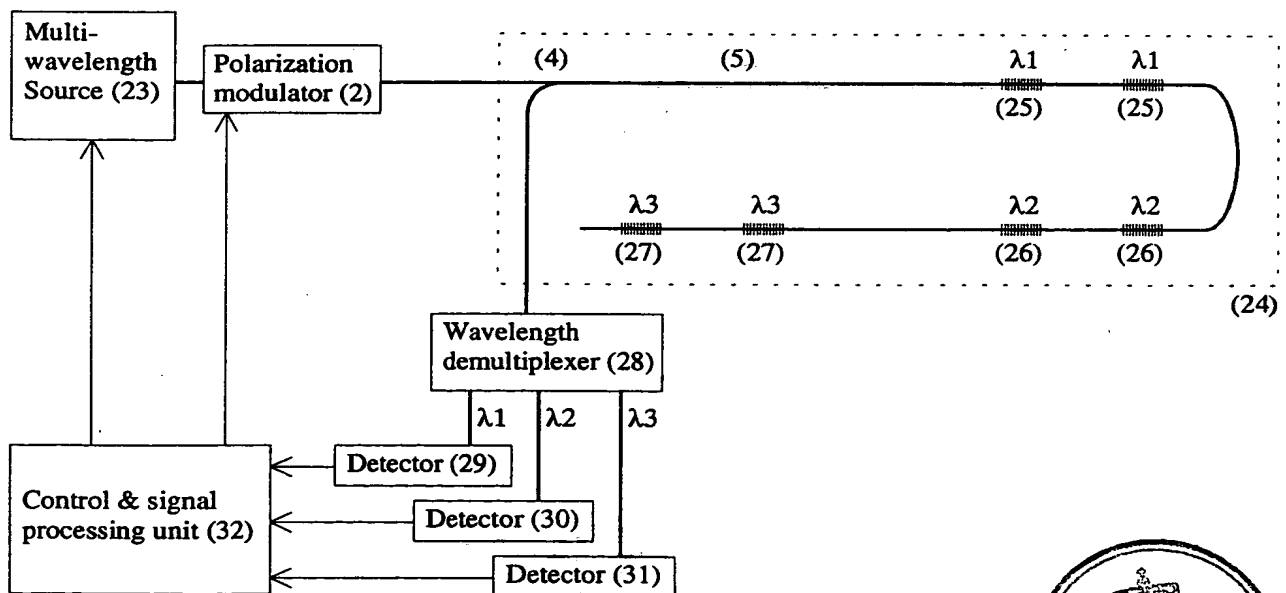


Fig. 4

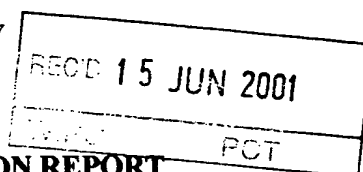


PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)



Applicant's or agent's file reference INT00110D	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/NO00/00219	International filing date (day/month/year) 22.06.2000	Priority date (day/month/year) 23.06.1999
International Patent Classification (IPC) or national classification and IPC ₇ G 02 F 1/01		
Applicant Optoplan AS et al		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of _____ sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 02.01.2001	Date of completion of this report 22.05.2001
Name and mailing address of the IPEA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. 08-667 72 88	Authorized officer Sture Elnäs/MN Telephone No. 08-782 25 00

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/NO00/00219

I. Basis of the report

1. With regard to the **elements** of the international application:*

- ☒ the international application as originally filed
- ☐ the description:
 pages _____, as originally filed
 pages _____, filed with the demand
 pages _____, filed with the letter of _____
- ☐ the claims:
 pages _____, as originally filed
 pages _____, as amended (together with any statement) under article 19
 pages _____, filed with the demand
 pages _____, filed with the letter of _____
- ☐ the drawings:
 pages _____, as originally filed
 pages _____, filed with the demand
 pages _____, filed with the letter of _____
- ☐ the sequence listing part of the description:
 pages _____, as originally filed
 pages _____, filed with the demand
 pages _____, filed with the letter of _____

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language _____ which is:

- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. ☐ The amendments have resulted in the cancellation of:

- ☐ the description, pages _____
- ☐ the claims, Nos. _____
- ☐ the drawings, sheet/fig _____

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2 (c)).**

* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

** Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.



INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/NO00/00219

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**1. Statement**

Novelty (N)	Claims	<u>1-13</u>	YES
	Claims		NO
Inventive step (IS)	Claims	<u>1-13</u>	YES
	Claims		NO
Industrial applicability (IA)	Claims	<u>1-13</u>	YES
	Claims		NO

2. Citations and explanations (Rule 70.7)

The claimed invention relates to a method and an assembly for elimination or reduction of signal fading in optical interferometer networks.

The invention is intended to solve the problem of polarization induced signal fading, and where the method can be used to interrogate WDM, TDM or SDM networks.

The solution according to the invention comprises modulating the polarization state, receiving the signals from different paths and processing by determining the phase difference between the signals.

Documents cited in the International Search Report:

US 5173743
US5351124
US4897543

The cited documents describe fiber optical interferometers with polarization fading control.

However, none of the documents describe a device for reduction of signal fading by determining the phase difference as defined in the claims.

Accordingly, the claimed invention fulfils the requirements of novelty (N), inventive step (IS) and industrial applicability (IA).

